§4. Control of Divertor Heat Load by Real-time Magnetic Axis Swing in Steady State Operation

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Significant progress has been recorded at LHD. In high power operation with a combination of ICH, ECH and intermittent NBI, the plasma with the temperature of more than I keV has been sustained over 31 min 45 sec. Steady-state divertor operation unlike limiter discharges in TRIAM and Tore Supra has been achieved.

Long pulse discharges with the heating power of less than 1 MW have been successfully achieved over 2 min. However, an uncontrollable density increase due to outgassing from divertor components was observed, when the injected energy exceeded about 75 MJ. As a result, the plasma was terminated by a radiation collapse. Strong nonuniformity in divertor heat flux distribution along divertor leg trace was observed. Such a toroidal nonuniformity is connected with the existence of ergodic region just outside the last closed flux surface (LCFS), which depends on the magnetic configuration (magnetic axis). Therefore, in 2004 experimental campaign, an optimum toroidal repartition of divertor heat flux has been attempted by changing the magnetic axis and it has enabled us to access a steady-state regime with a safety level for actively cooled divertor plates.

Figure 1 shows the dependence of divertor heat flux on the magnetic axis. We measured the temperature increase of divertor plates located at the inboard and top of the torus for the discharges with the same plasma parameters in different magnetic axis. In the inward shifted configuration (R = 3.6 m), the divertor flux is concentrated on the inboard side as expected by calculation. As the magnetic axis is moved outward, the concentrated location changes from inboard side to top one. From this figure, it is found that it might be reasonable to operate in the magnetic configuration with R = 3.65 –3.7 m from the view point of non-localization of divertor heat flux. The optimum operatonal regime for steady state operation was explored by changing the magnetic axis during the discharge. As a result, thirty minutes discharges were achieved by using a new technique of real-time magnetic axis swing within R = 3.67-3.7 m. In those discharges, the divertor heat flux was dispersed along the divertor leg trace as shown in Fig. 2. The concentration of heat flux observed on the inboard side of the torus, in particular, near the ICRF antennas, was evaded and all measured divertor temperatures were reduced within 200 °C, which is a safety level of actively cooled divertor plates. Power balance in the divertor was also analyzed by using a calorimetric method, in which the exhaust power is measured with the difference between the input and output water temperatures and the flow rate. The cooling channel is divided into ten sections along the divertor trace and passes through the inboard and the outboard sides of the torus alternately. Figure 3 shows the distribution of divertor heat load along each divertor leg trace. We can find that there is still a nonuniformity in the divertor heat flux. This may be related to the loss of high-energy ions accelerated at the ion cyclotron resonance layer near ICRF antennas. The particle orbit calculation is now under investigation. The total power exhausted in the divertor is 310 kW and the radiation power is 102 kW. The averaged injection power can be estimated to be 425 kW from the absorption efficiency for each heating method. The energy flow through the plasma is almost completely accounted.

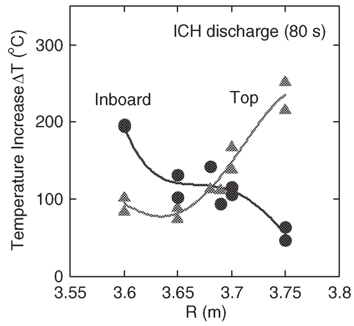

Fig. 1. Dependence of divertor heat flux on Magnetic axis

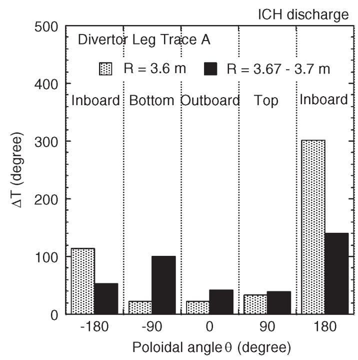

Fig. 2. Repartition of heat flux along a divertor leg trace

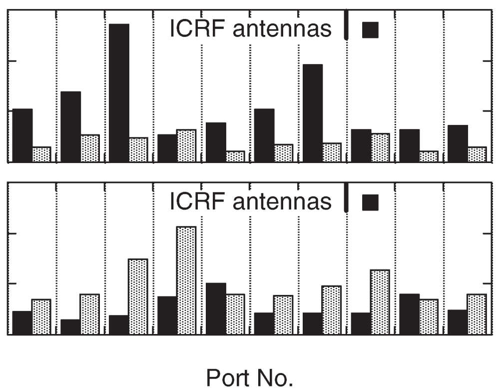

Fig. 3. Distribution of divertor heat load along each divertor leg trace